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Bridging the digital divide for e-learning students through adaptive VLEs

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Abstract - Virtual Learning Environments (VLEs) are required to be highly effective and easy to use as they serve as the primary institutional portal between students and academics. There are currently a number of challenges that are caused due to the modernized digital divide, with a significant limitation being the inability of information systems to adapt to the users' technological platform, broadband quality and device in use to access the online system. This paper focuses on the limitations that students encounter when accessing VLEs within Higher Educational Institutes (HEIs). This research aims to primarily review and provide critical analysis of current VLE frameworks, as well as assess restrictions based on several demographics including content adaptation and technical aspects. An algorithmic system is developed to analyze students' individualistic needs, undertake adaption and personalization of the VLE, and hence ensure consistent and efficient access to academic web resources and functionalities.

Keywords—digital divide, e-learning, adaptation, customisation, VLE, optimisation

I. INTRODUCTION

The concept of digital divide is well-established amongst the IT industry and mainly refers to the gap of unequal accessibility and experience when using information systems (IS), commonly due to a set of demographics [1]. This topic has been widely studied over the years [2-7] and various methodologies have been proposed, aiming at reducing the digital gap experienced in different industries. This inequality is still pertinent and active in all sectors, particularly within the educational context. This paper focuses specifically on the inequality experienced by students during their academic studies when accessing and working on their higher educational institution's VLE. With the augmented drive from HEIs towards e-learning, this IS platform is nowadays evermore critical as the students' main repository for accessing academic material and communicating with peers.

Due to the inherently diverse technological resources and working environments however, students are commonly subjected to different user experiences which consequently create inconsistent usage practices and ultimately result in inefficient VLE usability. This limitation is noted when online elements and features are not presented appropriately, which can be due to a number of factors such as device type, broadband connection, software availability and server configuration. The

aim of this paper is to analyze these VLE limitations and present a viable and evaluated solution to bridge this digital divide.

II. LITERATURE REVIEW

The unequal access to information systems for distance learning students has been studied intensively over past years through different demographics and metrics, which are resulting in different stages and interpretations of the digital divide. These have primarily moved from digital "have" versus "have-nots" towards a more social and intellectual inequality [2].

A. Modern Digital Divide

The modern digital divide is not a question of whether users possess the right technology at hand, however with new technology being constantly introduced in the market, discrepancies arise which in turn cause a new form of divide. Analyses on digital gaps noted in different regional dimensions conclude that there is still a high level of imbalance even in developed countries [3]. This urges the requirement of mitigation actions and highlights the additional efforts necessary to provide viable proposals in order to narrow the digital gaps even further. A very recent study [4] looks into the historic evolution of the digital divide across a set of countries in the EU in order to examine the effectiveness of latest mitigation techniques and policies embedded in relation to this subject. Through the use of a set of factor indicators to assist with the analysis of statistical data, it has been concluded that notwithstanding the advancements registered, the digital gap between the respective countries has been stable with alas very low rate of reduction [4]. This may arguably be the result of emerging technologies that are continuously being introduced to the industry and in turn result in a wider digital gap.

Digital divide studies have included mathematical measures and analysis to gain more insight on the penetration of broadband services and its infrastructure, and the latter are considered key in developing and providing foundation for any information society [6]. An interesting research [7] in this regard was carried out on broadband adoption within certain countries and by formulating the relative penetration and digitization model [5] of each country, a derivation is made on the digital divide gap that is analyzed with estimates on broadband convergence.

Within the educational sector, institutions are constantly required to strengthen and utilize the technology in teaching and learning processes [6]. Factors that affect this have been set by identifying the importance of policy measures to stimulate growth in this domain [8]. These factors include the effects on content, infrastructure, demand, supply, governments and education. The study highlights that two levels of competition form an important parameter towards equal penetration of broadband services, these being different infrastructures and operators. It has been noted however that once the right supply infrastructure has been put in place, it seems that the issue shifts towards a higher focus on the demand side [8]. This highlights the fact that apart from technical and economic parameters, successful implementation of broadband services also depends on the kind of public policy measures taken to stimulate the demand and facilitate penetration. The publication suggests two methods of achieving such measures, which are upgrades of information technology skills and content development [8].

B. E-learning

The continuous shift to adapt emergent technologies implies that web applications are no longer utilized as mere content repositories but rather as intelligent and resourceful systems that are proficient and adaptable for users. In the education sector, current learning platforms are complex and lead to confusion on both the student and teacher's part. The widespread diffusion of e-learning and m-learning platforms, which furthers new opportunities of effective learning in a flexible manner [9], allow students to make use of a number of portable devices to access their education repository and enrol onto a programme. Overcoming the digital gaps that e-learning students are exposed to is a challenging task, and many argue that a first step towards mitigating this aspect is by ensuring that academic teams are making full use of educational resources that are made available to them [10] [11]. This builds on the argument presented by [12], that VLEs help mitigate the impact of emergent technologies in education and will be much more effective once resistance to the adoption of such technologies is reduced. Hence, VLEs will cease to be used solely for traditional lectures and be backed up with additional online learning material eventually making them the main source of learning resources for students [13].

The new digital divide is taking a different shape as we evolve in our technological knowledge and exposure, particularly with social networking weaved evermore as integral part of today's lifestyle. This theory has been well argued and recent studies [14], [15] conclude that the unequal access to information systems is no longer solely due to connectivity and infrastructure; however also consider innovative technology and devices being used. The high dependency on mobility is leading to a faster adoption of digital technologies and is therefore presenting new dimensions to the notion of digital divide [16]. It is noted that m-learning is considered as a prominent technology and constitutes a large portion of education [17]. This has been studied [18] through a cohort of younger students and yet noted several limitations including the lack of tested web applications' scalability and a coherent network infrastructure. One of these studies' main conclusions is that the divide based on ownership of

smartphones has been decreasing yet the demand to utilize the user's experience is increasing [18].

C. Adaptation of systems

Software adaptability has been an emerging need for business environments and has shifted the focus from efficiency towards opportunity, aiming at more coverage of user requirements, targets and resources. There are a number of aspects relating to system adaptation, including having an interactive yet individual design that would be instrumental to produce a more adaptive system. The goal is for a system designer to create an intertwined format for appropriate user interfaces, interaction strategies, web structures and presented content [19]. Additionally, this would include considerations for users' support level, cross-platform compatibility as well as appropriate technical skills [20]. These scholars highlight the need of adapting and optimising educational platforms, and hence resulting in appropriate self-directed learning tools.

As mobile learning is vastly increasing in popularity and usability, optimising techniques are proposed to enhance student experience by considering lack of reliable resources and high-speed connections [21]. Learning platforms are developed to bring forward more personalized output to users through system optimisation for maximised efficiency in e-learning [22].

Research has been conducted recently that aims at adapting information systems to end users with disabilities [23]. As part of the EU4ALL framework [24], such mitigation involves the design of an integrated system that displays the most appropriate output to the user. Through localized modification of a VLE's digital content, adapted views are provided conforming to the learning activity and device used. This has led numerous VLEs, such as the popular Moodle, to adopt optimization techniques [15], which are based on previous research on context-aware mobile computing [14]. This is achieved by studying the user's environment for personalization although it only considers the connection speed which does not constitute a realistic execution.

D. Customization of web applications

Cloud computing is a consistent parameter within the IT sector. By working through an intensive analysis on cloud computing services, research has been conducted to investigate the outcomes of customizing learning environments [25], [26]. Whilst the authors conclude that more flexibility and cost reduction would be produced, consideration to the added burden on the institution's networking system is not given. Other studies do consider the infrastructure aspect when customizing applications however conclude that restrictions are present in user adoption [27] and network scalability [28]. A detailed technical overview of cloud computing has been presented and considers the positive and negative aspects [29], with common disadvantages noted being the lack of scalability, security issues, and network traffic. This led the authors in [30] to argue that cloud computing is not yet proficient enough to cope with all issues and should be considered to tackle specific ones.

An innovative approach to reduce digital divide is proposed through multi-collaborative customized systems that are created using Web Service Definition Language [31], [32]. This optimizing technique looks into web interface elements and assigns horizontal or vertical associations for appropriate alignment and display. The latter proposed technique adds a dedicated set of resources and infrastructure for different user groups that mitigates the need of more customization and scalability. This technique however acknowledges the lack of consideration to the user interaction as no user experience improvements have been produced from such approach. An alternative study tackles this by giving clients more flexibility through dynamic composition and migration of desktop sites onto mobile versions [33]. This is done by having end users select the desired web elements and content. User tests carried out on this framework suggest that alas, the selection technique lacks intuition and is described as a complex workflow.

III. PROBLEM DEFINITION

Following the detailed insight and background research compiled, it seems that the analysis of digital divide within education is still lacking suitable implementations. Using this research, an executable solution is proposed in order to improve student learning experience and bridge the differences within technology diffusion amongst different demographics [34], [35]. Ultimately, an intelligent system should be concluded for students to access a dynamically optimized VLE which takes the appropriate academic elements into high consideration. Current limitations reported in literature include difficulties when accessing, loading, viewing, downloading and uploading academic material onto these platforms. These limitations can potentially lead to a number of negative resultant repercussions such as student discouragement, duplication of administrative work and missing coursework submissions.

When analyzing the technological and physical resources available to students, certain elements may not be sufficient to load the full VLE repository in a timely and appropriate manner as required. A partial mitigation to the problem is the increasing development of mobile versions for websites. This function would adjust the site's content in a different alignment that suits the portable device better. Although this is an improvement, digital gaps are still experienced due to other challenging factors such as the personalization of web elements [22]. Through the review of a number of proposed frameworks, certain demographics should be prioritized when customizing a learning platform that include the study of the user's geographical location, the utilized device, portability, screen size and resolution, bandwidth and network latencies, operating system and browser in use.

IV. PROPOSED SOLUTION

Bridging the experienced digital divide by using adaptable VLEs is recommended within this study. The proposed framework studies the user's working environment through a device test and stores appropriate information for the intelligent adaptation of the system. This considers three main aspects; the device in use, broadband connectivity and other generic system attributes. A system prototype has been developed using JavaScript, HTML and CSS as main languages. Web pages are

created to represent typical functions embedded within VLEs, and are optimized for different working environments.

The customization initiates once a student logs onto a VLE, upon which an authentication prompt is displayed for authorization of the device test. Data is recorded through browser cookies at different time-frames as appropriate. These firstly store information on the date and time of authorization, which is logged within a cookie and is activated for 24 hours as shown in Fig. 1. This will avoid prompting for re- authorization when a student navigates through the system and creates new sessions within this timeframe. In cases where the user refuses the device test to be carried out, the system header is instantly loaded and triggers the rest of the default VLE to load.

The use of browser cookies has also been embedded with a time-frame to log data regarding connectivity speed checks. In order to reduce the need of these calculations to be held upon each page refresh, cookie logs record the user's speed and does so at 15 minute intervals so as to avoid having checks constantly done. This algorithm, presented in Fig. 1, maintains an adapted VLE provided that the connection is stable.

```

Get user authorization reply
IF authorized
    Get date and start time of authorization
    Set expiration to 24 hours
ELSE
    Get date and time of authorization
    Get connection speed result
    Set expiration to 15 minutes

```

Fig. 1. Prompting for user authorization and setting browser cookies for authorization and connection test

A. Device Properties

The device check initiates with a study of the user's device being in use when accessing and using a VLE. This process starts with a confirmation of whether the device is a portable one, or whether it is a desktop machine. A study of whether full desktop view would be supported on the particular device is also carried out. Screen dimensions are measured in order to define how web elements should be displayed and determine if any should be omitted from loading.

A tool that assists with the identification of information about the user device is a JavaScript file called Wireless Universal Resource File (WURFL). This file incorporates a number of functions that call different bits of user data, such as 'WURFL.is_mobile' and 'WURFL.form_factor' that return information on whether the device is a mobile or desktop, and more specifically the type of device such as Smartphone. Based on the outcomes, a mobile version of the default or adapted VLE loads as appropriate which includes more touch-friendly interaction with the system and enhanced menu display. Other minor adaptations are held through the consideration of screen dimensions, in case of a portable device. Through Cascading Styling Sheet commands, web elements subsequently placed and displayed as appropriate.

B. Connectivity Properties

The device check proceeds with broadband analysis whilst amalgamating other logged user information. This next check

is done by studying the user's connectivity speed, which is a measure of the time taken to load a site. A viable estimate of the loading time is collected by requesting to load a sample JPG file such as the site header, which is large enough to produce a highly accurate measurement of the connection yet not computationally excessive that would ultimately affect the responsive loading time. On the other hand, having a file that is of very few bytes would not be sufficient as no calculation difference would be detected. The measure of loading this sample image ultimately allows for the calculation of the user's connection speed, as shown in Fig. 2, which is assumed to be mainly equivalent to the download speed since VLE upload functions are only occasionally used.

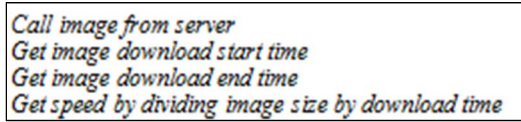


Fig. 2. Loading sample image and calculating speed

The calculation of a user's connection speed is done by dividing the sample image size by its loading time. This process also determines a threshold that considers what the minimum appropriate user speed should be, in order to assess whether the connection is sufficient to load the full VLE elements or load less and lower resolution objects. This is calculated by dividing the actual size of the default VLE site by the acceptable load time. Through additional research carried out to determine what the standard acceptable load time is [36], it has been concluded that ideal loading time for this system is set to 3 seconds. Ultimately, through these calculations and settings, the user's connection speed is measured as outlined in Fig. 3. In case this is lower than the agreed threshold, the platform amends large demanding features including videos and images, as well as omits any inessential web features such as calendar and any advert or extra panels.

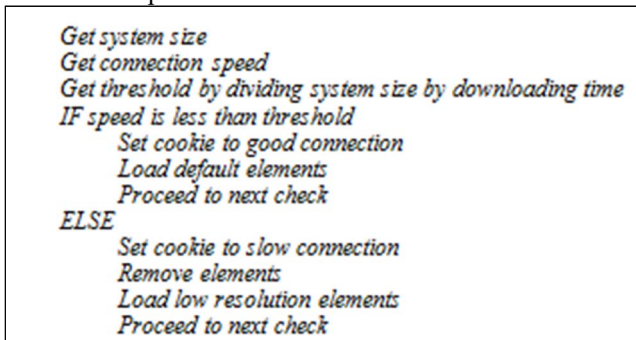


Fig. 3. Setting connection threshold and determining the status of the user's connection

The development of this prototype is based on the assumption that the system is of 15Mb in size, therefore the minimum connection speed required would be at least of 5Mbps when considering that the site should be loaded in 3 seconds. The algorithm determines whether the user's connection is sufficient to load full VLE elements or otherwise, and proceeds to work on web elements' resolution as required. By default, the system provides high quality elements, however lowers their resolution should a slower connection is detected. This is done

in order to ensure that the connectivity burden is reduced for a more appropriate user experience.

C. System Properties

Following the study of the physical and broadband resources, the test proceeds to analyze the operating system and browser in use. Such properties determine whether the student should have a standard font displayed, or whether the defaulted sophisticated font type is to be loaded. Web styling may be altered based on the type of browser and version in use, as certain outdated browsers do not support new web styling and therefore require alterations.

Analyzing the operating system in use, determines how text on the learning platform is to be presented. In cases where a non-standard operating system is used, this results in the default system font to not be compatible with the user's properties. A Mac computer for example has different text smoothness when compared to a Windows machine [37]. This mitigation prevents the end user from experiencing a cluttered page. Additional research on appropriate fonts suggests that Arial and Verdana are amongst the most legible fonts, with Verdana being the most preferred [38]. This is therefore set as the default system font however web pages are configured to an Ariel font should a non-standard operating system be detected during the device study. Moreover, browser analysis result a prompt when Internet Explorer in particular is detected which states that certain elements and features may not be displayed or function appropriately, and recommends the use of other browsers. Should this browser be in use, an additional statement within CSS imposes the HTML objects towards a 'block' display to section web elements more effectively.

Through the study of the discussed adaptation based on different properties, an adaptive and personalized VLE is displayed that is explicitly in line with students' available resources. All data collected through the algorithmic process discussed are amalgamated together in an intelligent manner in order for the system to detect what is the best possible outcome. The flowchart in Fig. 4 below provides an overview of the process being undertaken when VLE adaptation techniques are activated as drivers to bridge the digital divide in this domain.

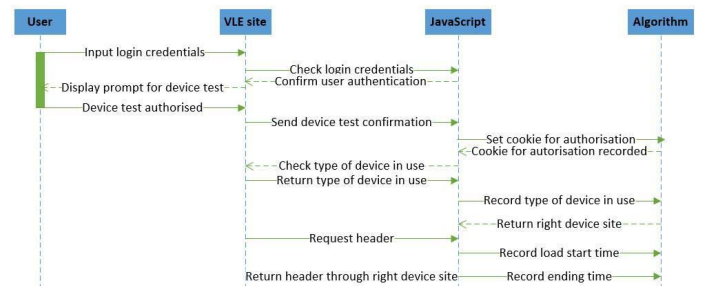


Fig. 4. Part A of sequence diagram

The sequence diagram above presents an overview of how data is managed during the first section of the adaptation process. This highlights how authorization is requested and reviewed, and then initiates the device test by analyzing the device and start connectivity calculations.

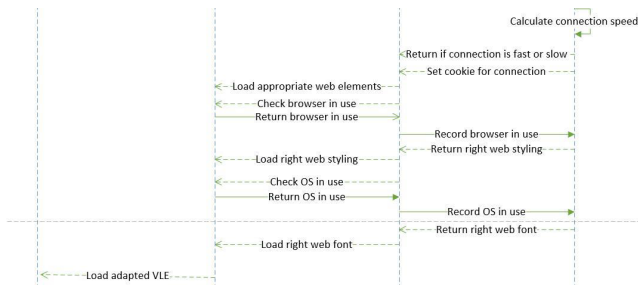


Fig. 5. Part B of sequence diagram

The second part of the diagram displays internal messages that record calculations carried out on the user's connection speed. Decisions are taken and cookies set accordingly. Further tests are carried out to review the browser and operating system in order to proceed and load the adapted VLE.

V. RESULTS AND DISCUSSION

The outlined proposed solution has been developed and evaluated through the prototype system built that is 15Mb in size and therefore requires a minimum connection speed of 5Mbps. Different conditions have been applied for properties discussed. The evaluation carried out also considers the system's functionality in terms of effectiveness and usability, including user authentication and operation results returned during the study. The main consideration is to review different adaptable techniques based on a number of working environments when accessing the platform. Throughout this implementation, certain decisions and assumptions have been made to present a viable solution to bridge the digital divide when working on a VLE.

A. Device check

The adaptation algorithm initiates by checking the student's physical device that is in use. Two versions of the system prototype have been developed in order to display appropriate adapted VLEs for mobile and standard desktop devices. The desktop site includes standard web elements as a default VLE would display, as demonstrated in Fig. 6 whilst the mobile version consists of touch and user-friendly features including the consideration of screen dimensions, as shown in Fig. 7. Once the type of machine in use is determined, the relevant site is loaded while carrying out further optimization techniques as required.

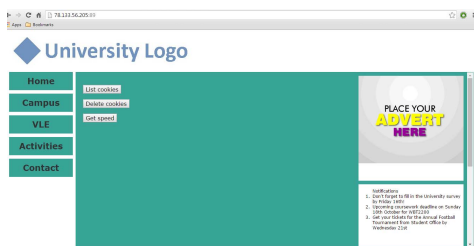


Fig. 6. VLE home page using desktop machine

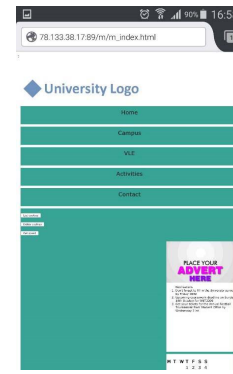


Fig. 7. VLE home page using smartphone

B. Connectivity analysis

This process starts calculations by reviewing the site header's download speed when considering the overall system size and header file size. This calculation is held to measure the start and end time of the server ping and receiving the sample image which is collected. This provides sufficient information for the process to perform the appropriate calculations and analyze the user's connectivity state, as displayed in Fig. 8 below.

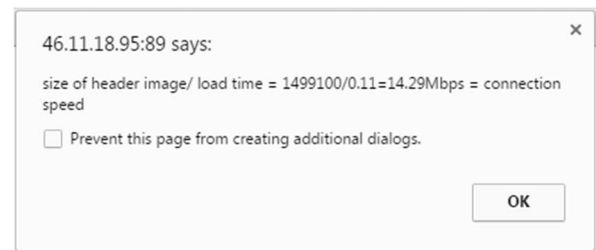


Fig. 8. Outputting the connection speed

This process of downloading a portion of the site for testing is mandatory in order to analyze the connectivity state. This ultimately provides a speed threshold which is required to determine whether a connection is sufficient to load the default VLE or otherwise. Amendments are activated in cases where a slower connection is detected, which are aimed at enhancing the online navigation and page response time. Low resolution elements are also presented in such case although this condition does not consider different ranges of speed to display different levels of low resolution components.

C. System review

Additional checks are carried out as part of the adaptation process, by reviewing the browser and operating system in use. This identification provides the adaptation process with a more thorough understanding of the student's working environment. The browser is checked to look out for the use of Internet Explorer. Even though this browser is conventional, it is considered slower and limits the level of customization for the end user, therefore the process displays a prompt and configures its web styling sheet to arrange elements in blocks of paragraphs so as to avoid overlapping and unstructured features. This is presented in Fig. 9. Such process may in time become inessential as Internet Explorer is working on enhancing browsing experience.

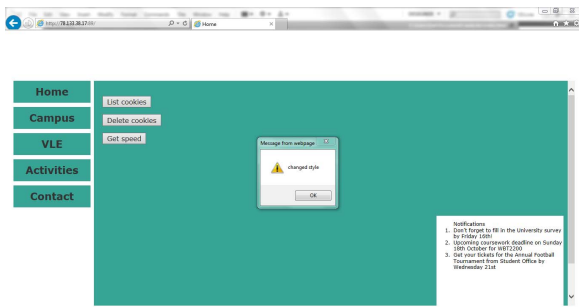


Fig. 9. Changed web styling and reduced objects due to use of Internet Explorer and weak connection

The study of the operating system is done to determine whether a change in the system font is required. The default system prototype is based on Verdana font as it is considered as one of the most preferred web fonts at the time. On the other hand, Arial is the traditional and safest font which is used in case a different operating system is detected. This adaptation has been tested on Windows, Linux and Mac OS software, as shown in Fig. 10. This adaptation condition is executed in cases where the student's device is not equipped with one of these standard operating systems.

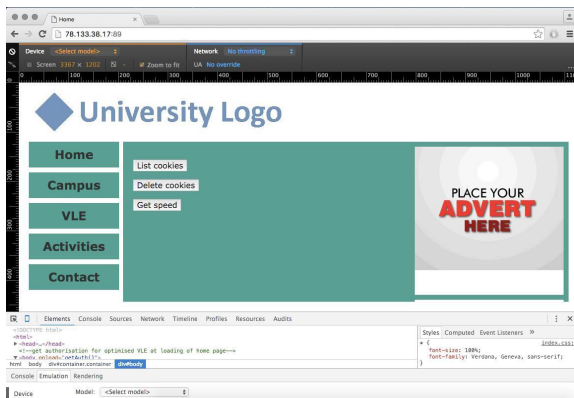


Fig. 10. Default font displayed when using Mac OS

A number of test cases have been carried out to represent different working environments, starting from the usage of a desktop machine with a very good connection speed and using a recommended browser and standard operating system. Such test resulted in the default VLE to be loaded in full since the connection speed and other properties were sufficient. Should the same conditions be kept however having a relatively weak connection, as was the case in Fig. 11, the system removes the calendar and advert web objects and also loads low resolution elements on all pages.

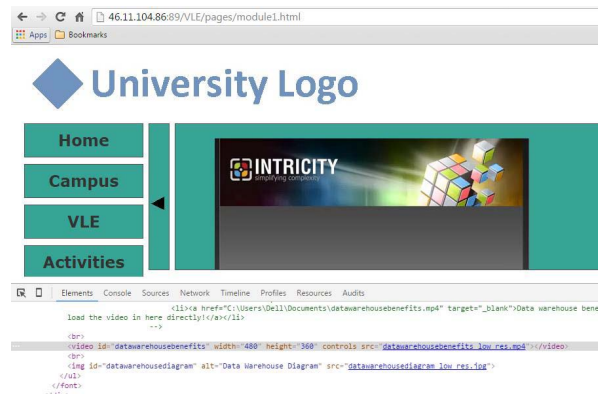


Fig. 11. Low resolution elements loaded

Test cases that presented a non-recommended browser displayed the full or adapted VLE, based on their connectivity detection, and amended the page styling as well as displayed a prompt shown in Fig. 12.

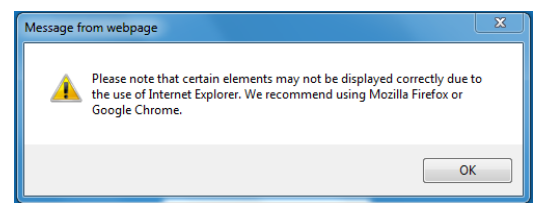


Fig. 12. Prompt displayed when detecting Internet Explorer

A smartphone was used to also replicate different working environments by going through different connections and other properties. The adapted VLE shown in Fig. 13 presents a mobile view that reduces web objects and loads lower resolution elements due to a weak connection.

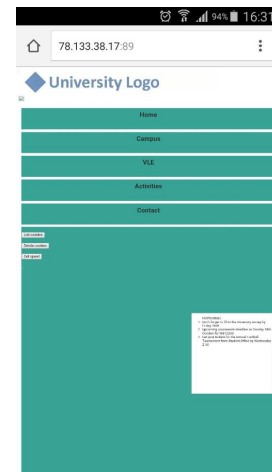


Fig. 13. Adapted VLE using mobile phone

Whilst the future of technology is difficult to predict in terms of devices capabilities and features, the current trends of portability seem quite mature. Further innovative technologies that may increase in popularity amongst students may be included within this implementation using new WURFL deployments that recognize any respective new device properties. Additional development may then be required

accordingly; however identical algorithmic approaches would be applicable.

D. Usability of browser cookies

The use of browser cookies is highly required for the system to log certain information on authorization and connectivity. These have been embedded in the system in order to hold two logs. The user's authorization is primarily logged for ethical purposes prior to the test being carried out, as shown in Fig. 14. A record of the student's connectivity speed is also stored for approximately 15 minutes before this calculation is rechecked due to the possibility of the connection being unstable. This calculation is done in the background and does not disturb the user, provided that the test authorization is still active. For testing purposes, Fig. 15 presents one of the prompts that have been outputted during the process for cookie logs to be reviewed.

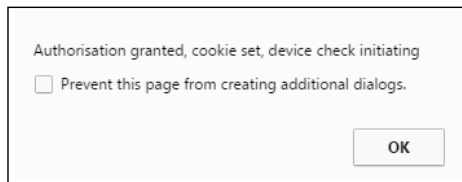


Fig. 14. Device test authorization granted

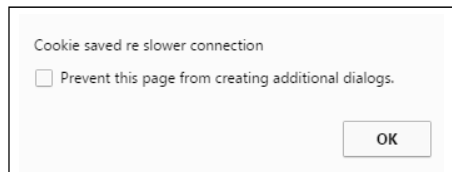


Fig. 15. Slower connection detected and logged

E. Technical assumptions

As per any prototype system developed to work on a set of algorithms, few assumptions have been taken for the implementation to work within the set conditions. The process initially assumes that a portable or desktop machine is available for the student to access a VLE, having a broadband connectivity available at the time of access. Provided that a mobile device is used, smartphones are required access and work on an online platform. Furthermore, it is assumed that the student's device is compatible with JavaScript. In regards to the connectivity test, it has been concluded that the ideal and acceptable page loading time is 3 seconds. This is appropriate for the time of research however such statistic may vary according to innovative technology as well as higher standards of web applications and broadband services.

F. System usability

The technology presented in this system is very user-friendly since students are not required to control any critical processes. User experience is highly considered when algorithms are executed in the background following the prompt to the student asking for authorization for the test. If this is granted, the device test is carried out and an adaptable VLE is shortly processed and displayed. The work done during algorithmic processes does not inflict a large amount of processing memory, therefore no apparent connectivity or

general delays are noted by the user. On the other hand, the optimization methods do require more robustness to evolve into a more effective system in terms of usability.

The proposed solution design stage has taken into consideration previous literature as well as student experiences. The implementation of a device test that is activated when students access VLEs is noted to provide appropriate optimizing techniques necessary to bridge the known digital divide, whilst maintaining appropriate web experience at a cost-effective approach. The system customization is done in real time through the use of effective algorithms, and no significant additional connectivity burden is impacted during the process. Future work may include additional evaluation by conducting surveys and holding observations of different users working on the system. This would gather useful insight on the effectiveness and collect general feedback from students who interact with the VLE through different demographics and working environment.

VI. CONCLUSION

A solution has been implemented though an intelligent algorithm that analysis a user's working environment and properties. Adaptation techniques are executed on a VLE for a more personalized and enhanced user experience. This is achieved following automatic data acquisition using device test scripts that review the student's working environment including device, connectivity and other system properties. The collected information is ultimately combined algorithmic for a successful adaptable VLE that aims at bridging the digital divide.

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